WOODCHIP FUEL BOILER CONVERSION

BROOKDALE NURSERIES

NEWCASTLE, N.B.

22

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C.R.E.D.A. Project 2024

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Canada/New Brunswick Conservation and Renewable Energy Demonstration Program

The Conservation and Renewable Energy Demonstration Program Program is administered in New Brunswick by the Energy Secretariat and managed jointly with Energy, Mines and Resources Canada. The Program is designed to help demonstrate promising conservation and renewable energy technologies, to develop public awareness and understanding of these technologies, and to create employment in new or existing industries.

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This final report is based on a project which was financially supported by the Energy Demonstration Program. For further information on other demonstration projects funded in New Brunswick under this program, contact:

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Ce rapport final est basé sur un projet qui a reçu une aide financière du Programme de démonstration. Pour de plus amples renseignements, communiquez avec la:

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1.0 EXECUTIVE SUMMARY

The wood chip burner demonstration at Brookdale Nurseries was implemented with the primary objective of reducing rapidly increasing energy costs by converting a boiler from fuel oil to wood residue. The technology demonstrated was wood chip burning, utilizing wood residue from local sources. Partial funding for the project was provided by the Conservation and Renewable Energy Demonstration Agreement sponsored by the N.B. Energy Secretariat and by Energy, Mines and Resources Canada.

Tests were performed during the 1983-1984 heating season to determine the performance of the owner-fabricated, wood-chip-fuelled, Dutch Oven burner retrofitted to a previously oil-fired, 250 hp boiler located at Brookdale Nurseries Limited, Newcastle, N.B.

Overall fuel consumption during the seven month monitoring period was 420 tonnes (460 tons) of 20% wet basis (25% dry basis) wood chips. Total production of low pressure (nominally 40 kpa or 6 psig) steam was 2,100,000 kg (4,625,000 lbs) from condensate supplied to the boiler at about 30°C (85°F). Spot checks of the system efficiency indicated 71% to 79% using the stack loss method, and 69.5% to 84.8% using the ratio of output energy to input energy. The system operated at a smoke number of 1, at which there were no visible emissions.

The boiler was found to be fired at 20-22% of its capacity, which reduced output is matched by a similarly low output from the Dutch Oven burner relative to its capacity.

Modifications to the fuel feeding system to increase the fuel feed rate, to the burner to improve distribution of fuel over the grate surface, and possibly to the combustion air supply system should make it possible to obtain a large increase in the output from this burner/boiler combination.

The entire system has performed well and has produced a cost saving of about 70% when compared to the previous oil installation. Simple payback was achieved in 1.9 years.

Information on the project has been distributed through Energy Secretariat publications, one-to-one consultations, a one-day seminar at the site, and through presentations on the project at other workshops and conferences. Interest has been considerable.

1.0 RESUME

Afin d'obtenir une réduction du coût énergétique par rapport au coût de production, on a installé un brûleur à copeaux de bois à la pépinière Brookdale.

La technologie démontrée, le brûlage des copeaux de bois, etait rendue possible en utilisant des résidus forestiers de source locale plutôt que d'importer du mazout. Le projet a été financé en partie grâce à l'Accord de démonstration des économies d'énergie et des énergies renouvelables patronné par le Secrétariat à l'énergie et Energie, Mines et Ressources Canada. Le projet consistait essentiellement en la construction d'une chambre de combustion avec chaudière hollandaise rattachée à la chaudière au mazout de 250 c.v. présentement en opération à la pépinière Brookdale de Newcastle, N-B. Une boîte en vrac des copeaux, une vis de déchargement et un assortiment d'appareils permettant un contrôle automatique ont été installés.

Durant la saison de chauffage 1983-84 des tests de performance ont donné des résultats très favorables. La consommation de copeaux de bois pendant les sept mois a été de 420 tonnes (460 tons) à 20% de base mouillée (25% de base sèche). La production totale de vapeur à base pression (40 kpa ou 6 psig) était de 2,100,000 kg (4,625,000 lbs) produit de condensé fournit à la chaudière au mazout à une température de 30°C (85°F). Le système a fonctionné avec une efficacité de 71% à 79% en utilisant la méthode d'énergie perdue par la cheminée et de 69.5% à 84.8% en utilisant le rapport d'énergie produite à l'énergie fournit au système. Le taux de fumée était de 1, nombre auquel aucune émission n'est visible.

La chaudière au mazout ne chauffe que de 20 à 25% de sa capacité actuelle. Cette réduction est aussi refletée par le rendement rendement de la chaudière hollandaise comparativement à sa capacité actuelle.

En augmentant le montant de copeaux de bois livré à la chaudière hollandaise, en assurant une distribution uniforme des copeaux sur la grille et en augmentant le montant d'air disponible pour la combustion, il est possible d'augmenter le rendement de ce système.

Le système en entier a presenté un excellent rendement et a permis une épargne de quelque 70% comparativement à l'installation au mazout qui était en place auparavant. En moins de 1.9 ans, l'on a recouvré l'argent investit.

On a présenté l'information de ce projet dans les publications du Secrétariat à l'énergie, lors de consultations individuelles, lors de conférences d'une journée sur les lieux et lors de présentations sur ce projet intégrées dans des ateliers et des

conférences. L'intérêt porté à ce projet a été des plus important.

2.0 INTRODUCTION AND BACKGROUND

Brookdale Nurseries is a family owned greenhouse operation, having established its roots in the market-garden business through vegetable transplants and bedding plants. It grew at a relatively fast pace for the first twenty years until 1973 when the first so-called energy crisis occurred. Facing almost unbearable price increases in oil, Brookdale began seeking an alternate source for heat.

Several types of fuel were considered, but wood and wood residue, being a natural resource and locally available, seemed to be the choice, particularly with Brookdale's geographic proximity to the wood industry in New Brunswick.

By the fall of 1978 oil prices had risen to the extent that an alternate source of fuel had to be adopted. An existing oil-fired boiler was modified so that it could be hand fired with three foot lengths of roundwood. Automation of the unit became necessary because hand firing was too labour intensive; it required refilling the fire-box about every thirty minutes. This need for automation led to the automatic wood chip fired boiler which is the subject of this report.

The performance objective of this project was to introduce and monitor wood chip burning and to assess it as an economically viable alternative to burning expensive imported oil.

3.0 DESCRIPTION OF DEMONSTRATION

3.1 General

Brookdale Nurseries Ltd. is located at the north side of the Town of Newcastle, and is accesible from Chaplin Island Road. During the 1983-84 heating season, 17 greenhouses were in use, and the foundations and frames exist to place an additional 12 others back in service, if required. Also, there are two large (370 sq. m./4000 sq.ft) retail display areas in the Garden Center, a 185 sq. m. (2,000 sq.ft.) Farmers Market, a tropical plant retail display area, heated office space, a packing room, stock rooms, a maintenance shop and connecting corridors.

3.2 Heating System

The entire greenhouse complex is heated by a low-pressure steam system which operates at about 40 kpa (6 psi.). An insulated, overhead pipe system is supplied with steam from boilers located in the two boiler rooms. Condensate is collected from the various buildings and returned to sumps in the boiler rooms for re-use. The front boiler room contains a 60 hp, oil-fired boiler and a 250 hp boiler originally operated on oil, but now converted to burn wood chips. The rear boiler room contains three 250 hp oil-fired boilers, one of which is in the process of being converted to burn wood chips; it was being hand-fired with roundwood in 3 foot lengths during the 1983-84 heating season. Boiler specifications are given in Appendix 3.

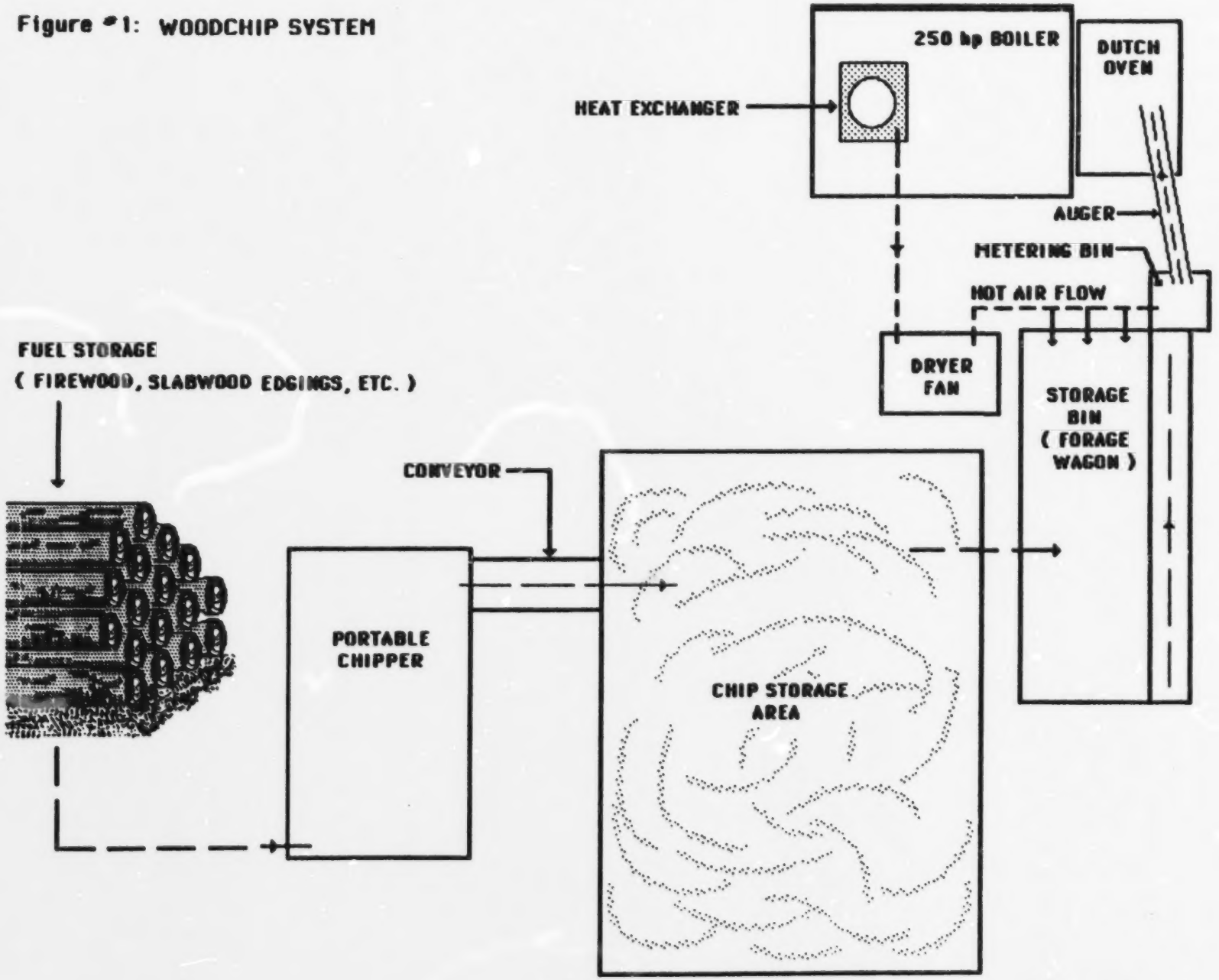
3.3 Wood Chip Conversion

The boiler was built by Dominion Bridge Co. Ltd. and is designated as model 250-06-3. It was designed for use with up to No. 6 fuel oil and a firing rate ranging from 3,500,000 btu/hr. to 10,500,000 btu/hr.

Conversion from fuel oil to wood chips was acnieved by completely removing the original oil burner and then constructing a Dutch Oven type of combustion chamber and installing it at the firing end of the boiler. Connection between the Dutch Oven and the boiler is through a refractory-lined collar (or fire ring) carried in a steel housing welded to the boiler front.

The wood chip fuel handling system was then constructed so that the Dutch Oven could be supplied with chips automatically from a large day bin whenever a drop in heating system steam pressure signalled a need for more heat from the boiler. The entire system is shown in Fig. 1.

Figure #1: WOODCHIP SYSTEM



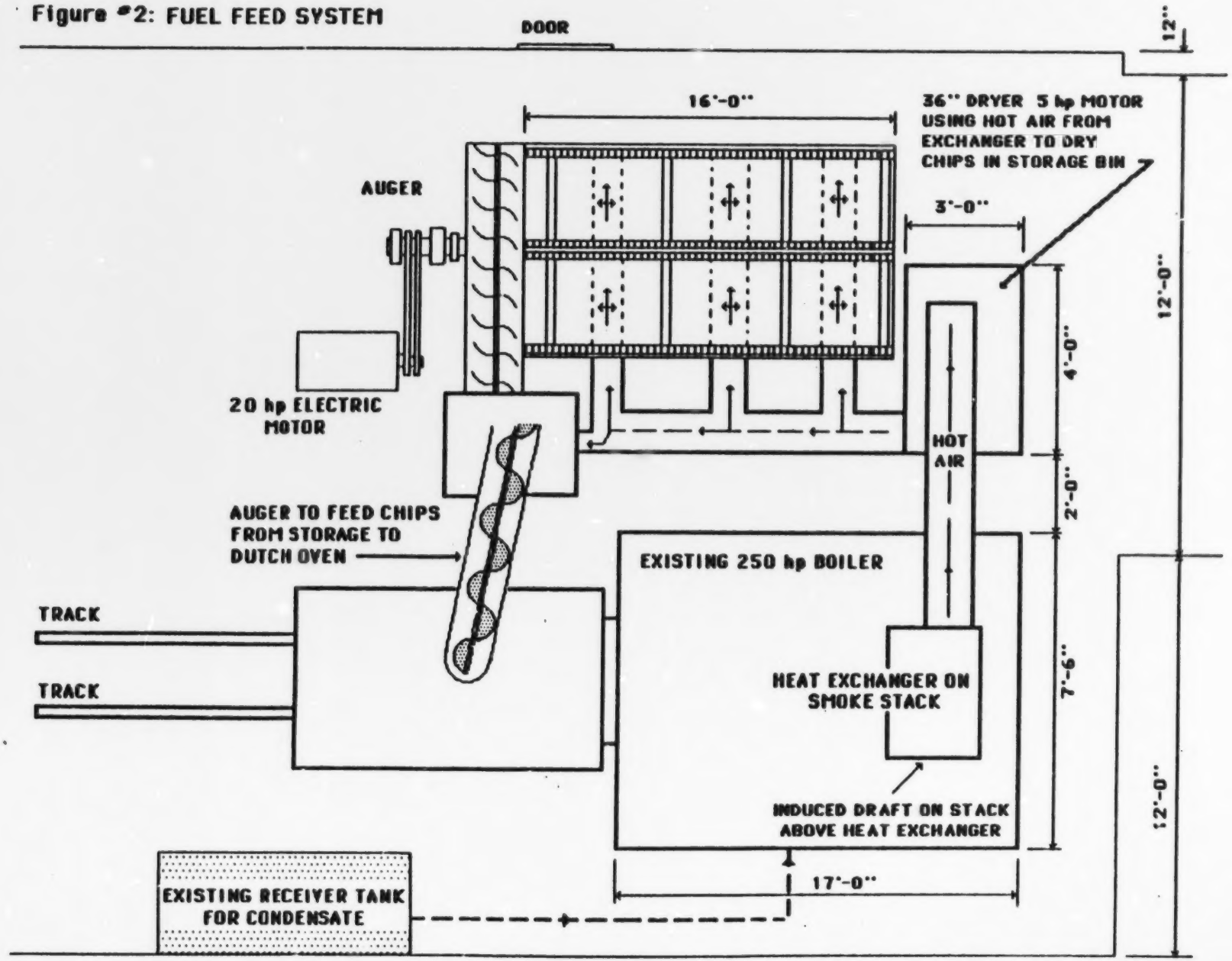
3.3.1 Fuel Handling and Feeding System

Chips are taken from a storage shed (located about 150 feet from the boiler room) by a conveyor system which transports the wood chips directly into a forage wagon mounted permanently beside the boiler. Provision was included to dry the chips by blowing hot air, obtained from a stack mounted heat exchanger, through them while in the forage wagon. Because this drying system was found to be ineffective, it is seldom used, and was not used during the 1983-84 heating season.

The forage wagon is equipped with a scraper chain live bottom which, in a normal agricultural operation, would be driven by the PTO of the tractor hauling the wagon; in this case, a 20 hp electric motor has been arranged to drive the live bottom. The live bottom delivers chips to a transverse screw conveyor (a standard component of the forage wagon) which, in turn, directs them into a small surge (or metering) bin. Diaphragm level switches in the surge bin are used to control operation of the live bottom/transverse screw conveyor so as to maintain a reasonably constant level of chips in the surge bin.

An inclined screw conveyor draws chips from the surge bin and supplies them to a rotary valve on the top of the Dutch Oven. Chips pass through the rotary valve and fall through a port in the refractory lining and onto the grate where they are burned. A chain drive from the inclined screw conveyor turns a short mixing auger fitted with left-hand flights at one end and right-hand flights at the other and installed within the surge bin; it serves to move chips in the bin to the intake of the inclined conveyor. The inclined screw conveyor is controlled by steam pressure such that, on a fall in pressure beneath a preset level (thus indicating a demand for heat), the auger drive is turned on and continues to operate, thus fuelling the Dutch Oven, until the preset high pressure limit is reached. The fuel handling system can be seen in Fig. 2.

Figure #2: FUEL FEED SYSTEM

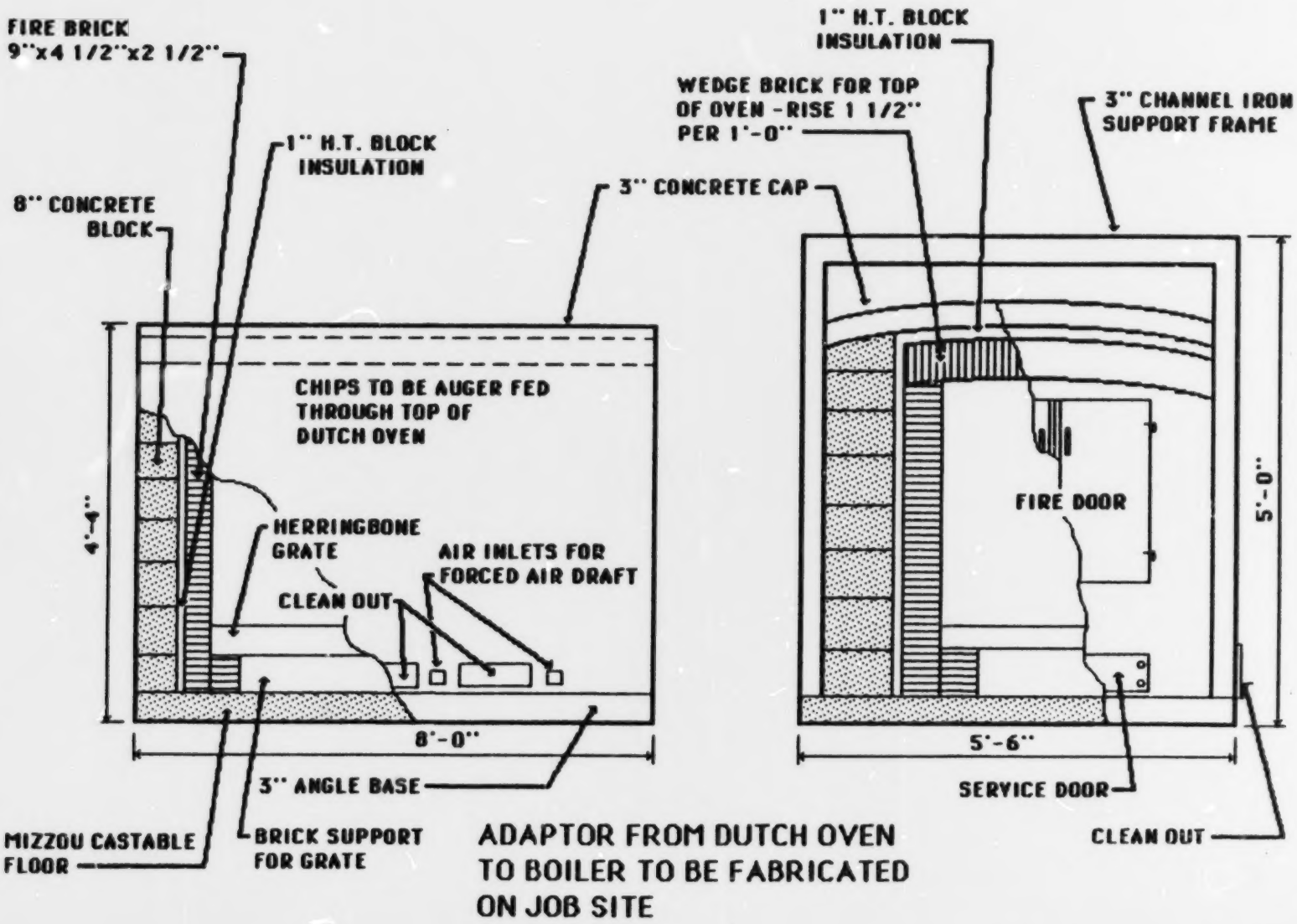


3.4 Dutch Oven

3.4.1 Construction: Dimensions

The frame of the Dutch Oven is made of structural steel sections and steel plate welded together into a box-like structure having overall dimensions of approximately 2.4m (8 ft.) long by 1.75m (5.75 ft.) high by 1.7m (5.5 ft.) wide. A schematic of the Dutch Oven can be seen in Fig.3. The frame is mounted on wheels which run on steel tracks bolted to the boiler room floor (see Fig.2). Within the frame, the bottom 0.3m (1 ft.) is used as the ash pit, and the cast iron grates are placed immediately above the ash pit at the 0.3m level. The uppermost 200mm (8 in.) serves as a combustion air plenum, where heat lost from the oven is used to preheat the combustion air. The combustion chamber walls are lined with insulating fire brick, and the ceiling is clad with a cast-in-place refractory material such that the inside dimensions are 0.98m (3.2 ft.) wide by 1.9m (6.25 ft.) long (to fire ring inner face) with the height of the arched ceiling increasing from 0.9m (3 ft.) at the sides to 1.0m (3.4 ft.) at the center. The horizontal grate surface is 0.9m (3 ft.) wide by 1.8m (6 ft.) long.

Figure #3: DUTCH OVEN



ADAPTOR FROM DUTCH OVEN
TO BOILER TO BE FABRICATED
ON JOB SITE

3.4.2 Fuel Feed

Chips are dropped into the combustion chamber through a hole in the top of the oven. They fall onto the grate where they form a pile over which burning takes place. An early attempt to spread the chips more uniformly over the grate surface by using a rotating, conical, cast iron deflector placed inside the combustion chamber a few inches below the bottom of the fuel feed hole was not successful because spreader life was unacceptably short.

3.4.3 Combustion Air Inlets

Ducts leading from the air plenum at the top of the Dutch Oven conduct primary (under-fire) combustion air to ports cut through the sides of the oven beneath the grate. Other ducts leading from the same plenum supply secondary (over-fire) air through similar ports, also cut through the sides of the oven, but entering the combustion chamber about 0.5m (1.5 ft) above the grate. Air distribution can be regulated manually by dampers in each duct. Placement of the air plenum immediately above the Dutch Oven serves to warm the combustion air while recovering some heat that otherwise would be lost to the boiler room.

3.4.4 Ash Handling

Whenever ash is observed to have accumulated to the extent that it could block air flow up through the grates, it is scraped out of the oven through access hatches located in the front and sides of the oven beneath the grate. Flyash tends to collect in the horizontal firetubes of the boiler and eventually blocks the flow of combustion gases to the point that smoke starts to leak from the oven into the boiler room. When this condition is noticed, the fire is allowed to burn out, the fasteners holding the oven to the boiler are removed, and the entire Dutch Oven is rolled away from the boiler with the aid of an electrically operated winch system. The firetubes are then cleaned manually using a conventional tube brush.

4.0 OBSERVATIONS DURING INSTALLATION AND OPERATION

Generally speaking, construction of this unit went quite well. Some trouble was encountered with the transfer of chips from the day storage bin to the metering bin. The day storage bin was raised so as to let chips flow down on the inclined auger rather than be forced against it.

Another problem was the bridging of chips in the metering bin. This was corrected by the installation of a cross auger to agitate and move the chips over the entry to the inclined auger.

5.0 PERFORMANCE MONITORING

Performance monitoring was the subject of a sub-contract with C.A. Short, P.Eng. Material from the monitoring report has been integrated into this report. Detailed information is found in Appendix 3.

The overall objectives of monitoring were:

1. to determine the total chip fuel consumption over a heating season
2. to determine the efficiency of the modified boiler
3. to make such observations and recommendations as may be of use to others who may wish to undertake modifications to their own heating equipement.

5.1 Monitoring Method

5.1.1 Measurement of Fuel Consumption and Energy Supplied

Prior to the start of the heating season, the fuel delivery rate of the final, inclined, auger was determined. This auger draws fuel chips from the small surge bin mentioned in 3.3.1 and so runs with reasonably constant infeed conditions relative to supply of the fuel; in other words, there is little or no tendency for the auger entry to become flooded with compacted chips at some times, and to become starved of chips at others. Consequently, it can be assumed that provided its speed is not changed and the size and shape of the chips is not varied, the auger will deliver a specific volume of chips per unit time. Since the auger tends to deliver a specific volume of chips per unit time, its performance was checked with the three different fuel types expected to be used during the heating season. The results of the delivery calibration tests are given in Appendix 3.1. Knowing both the volume of chips delivered per hour, and the bulk density of the chips being burned, a simple totalizing time clock wired to run whenever the auger is operated serves to measure, indirectly, the mass of fuel consumed over any particular time period.

Throughout the test period, samples of the fuel were collected and their moisture content and bulk density determined; results of these tests and details of the methods used are in Appendix 3.1 Total running time over any particular period of interest multiplied by the known auger volumetric delivery characteristic yields the mass of fuel supplied to the burner. Knowledge of the fuel's moisture content permits calculation of the mass of dry fibre delivered; this mass when multiplied by the higher heating value per unit mass of fuel gives the energy supplied to the burner.

5.1.2 Boiler Output

Boiler output was determined by measuring the volume of feedwater (condensate) supplied to the boiler, the feedwater temperature and the steam pressure. Feedwater was measured using a totalizing flow meter the accuracy of which was known prior to installation and was checked at the end of the test period. Feedwater temperature was measured at the condensate tank from which water is drawn by the feedwater pump; the dial thermometer used was calibrated against a thermometer of known accuracy prior to installation. The steam pressure gauge was calibrated using a dead-weight gauge tester, and a correction was established for it.

The energy used to boil the water to steam was calculated by multiplying the mass of water heated over the period of the test (from the flowmeter) by the enthalpy gained by the water in being heated from its initial temperature to that of dry, saturated (assumed) steam leaving the boiler at the recorded pressure.

5.1.3 Overall Thermal Efficiency - Output/Input Method

The overall thermal efficiency of the boiler is calculated by dividing the energy output as determined using the method outlined in 5.1.2 by the energy input over the same period of time as per 5.1.1. The resulting ratio, expressed as a percentage, represents the overall thermal efficiency of the boiler.

5.1.4 Efficiency - Stack Loss Method

The efficiency of the boiler was determined from measurements of gas temperature and percent CO_2 taken at the breeching connection (flue gas outlet) of the boiler. Such readings, used with the curves (Ref.1) appropriate to the fuel moisture content, give information relative to the amount of excess air being supplied to the burner and to its efficiency based on the stack loss method.

5.1.5 Test Periods

Instruments installed for the purposes of the monitoring exercise were intended to be read daily at about the same time of day. Such readings were taken for many days over the heating season, although lapses did occur at times due to other demands on the time of the operating staff. The readings taken are unfortunately not sufficiently complete to permit estimation of weekly and monthly fuel consumption patterns. The records for the months of November, 1983 and January and April, 1984 are the most complete, yet of these, only the January record spans the entire

month. However, within January, the data captured is not continuous in that three days were lost for unspecified repairs to the boiler, and at least part of a fourth day was lost due to failure and repair of the feed auger system; although steam production instrumentation continued to function, fuel consumption information is incomplete. More significantly, few if any fuel samples were taken, and those were not returned quickly enough to the laboratory for moisture content determination; therefore little is known of variations in fuel quality over much of the test period.

On three seperate occasions, boiler performance was monitored every few hours over a 24 hour period or over the total length of time the boiler was used during a 24 hour period. The three test periods involved were chosen near the start, middle and the end of the heating season. Over these test periods, combustion efficiency was determined frequently and fuel samples were collected to permit detailed determination of overall efficiency and detection of changes, if any, in boiler operation in the 24 hours and between different points in the heating season.

5.1.6 Performance: Firing Rate

The firing rate of the boiler is calculated based only on the data collected on the three 24 hour tests because of the frequency of data collection and freshness of the fuel samples taken then.

The firing rate is compared with the manafacturer's rated firing rate for the boiler, and with the potential heat output rate from the burner.

5.2 OVERALL PERFORMANCE RESULTS

Observations made over the 1983-84 heating season, and calculations made from these are presented in Appendix 3.4. The overall findings that can be drawn from the details in the Appendices are as follows:

5.2.1 Fuel Consumed Over Monitored Period

Based on measurements made and recorded observations, the total quantity of wood-chip fuel estimated to have been consumed over the 7 month monitored period is 420 tonnes of chips at a nominal 25% moisture content, dry basis (20% moisture content, wet basis

Three different types of fuel were used during the test period - dried cedar chips, dried hardwood chips and undried hardwood chips. The dried chips were made in June, 1983 and stored in a building adjacent to the chip-fuelled boiler house; this building has an air distribution system installed in it which makes it possible to force air through the chip pile. The air supply is controlled manually by personnel at the nursery, and is operated whenever air temperature and relative humidity are judged suitable. The cedar chips were made from wood that became available to the nursery operator at an attractive price, and were piled in front of the hardwood chips; the quantity involved was relatively small, and was largely consumed during the first few weeks of the heating season and prior to the start of monitoring. Due to an undetected failure of the fuel-feed monitoring timer in the first week or so of the intended monitoring period, it is not possible to provide a close estimate of the auger running time, and hence of fuel consumption, of the system when the cedar was being burned.

The dried hardwood chips were being used as fuel during the November monitoring site visit. and so, lacking records to the contrary, it has been assumed for purposes of fuel consumption estimation that these chips were used as from 83/10/24 when monitoring started. They remained in use until the supply was almost completely exhausted on 84/03/02.

The undried hardwood chips were made in late October or early November, 1983 from partly seasoned hardwood; they were chipped directly into an unventilated storage building located at the rear of the nursery site. The average moisture content was found to be 56.3% dry basis (36% wet basis) which indicates some drying relative to green hardwood chips which average 80% dry basis (45% wet basis). For this reason, these chips are not

designated as "green" hardwood chips in this report. Undried hardwood chips were used starting 84/03/02 until the boiler was shut down at the end of the heating season about 84/05/10.

5.2.2 Electrical Energy Used over the Monitoring Period

The electrical energy used to operate the fuel feed auger, forced and induced draft fans, feedwater pump, rotary air valve and all boiler controls was found to be 24,224 kWh. Energy used to operate the live-bottom day bin was not measured and is not included in the foregoing total.

5.2.3 Efficiency

Efficiency measurements based on the calculated ratio of output energy to input energy ranged from 69.5% with undried chips and at a low capacity factor of 45.9% to 84.8% with dried chips and at a capacity factor of 75.7%. These values are about 10% higher than expected. This may be due to under-estimation of the fuel consumed* (the fuel feed rate might be higher than that used in the efficiency calculations which were based on an average taken from four or five tests) and may also be due to the relatively low firing rate found to exist and hence the availability of a larger heat transfer surface area in the boiler relative to the quantity of heat to be transferred to the water. Also it has been assumed that the steam leaving the boiler was dry and saturated; if this was not in fact the case, then the calculated efficiency would be overestimated.

Efficiency measurements based on stack gas CO_2 content and temperature, ranged from 71% to 79% for all tests but one at which the CO_2 level of 3% was atypical (an observation supported by the high smoke number of 8 found at the same time) and at which the efficiency was too low to determine from the curves (Ref.1). These values, again somewhat higher than had been expected, tend to corroborate those determined above, and may be due to the low firing rate used. The relatively low stack gas temperature, which ranged from 240 F to 280 F, is quite likely due to the availability of a large heat transfer area relative to the firing rate, as mentioned above.

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* Tests conducted in February 1985 on the totaling timer used in monitoring indicate that, in frequent on/off service, it tends to start slowly and therefore reads low.

5.2.4 Emissions

Particulate and gaseous emissions monitoring was not a component of this study. Whenever the burner was operating at full fire, the smoke number was found to be 1, at which no visible emissions could be detected other than a plume of white water vapour in cold weather.

5.2.5 Firing Rate: Boiler

The Dominion Bridge Co. boiler with which the Brookdale Dutch Oven burner is being used is labelled by the manufacturer for a maximum firing rate of 10,500,000 btu/h and a minimum firing rate of 3,500,000 btu/h.

McLaughlin (Ref.2) states:

> Compared to conventional fuels, wood combustion requires more time for burning; requires more oxygen for complete combustion; and produces more moisture in the flue gas. Because of this, greater furnace volumes and grate surface areas per energy recovered per unit time are required compared to conventional fuel combustion systems. If a conversion of an existing boiler to wood firing is planned, then a downrating of capacity will normally occur.

Based on observations made during monitoring site visits and the subsequent calculations shown in Appendix 3.5 which assume a derating to 70% due to wood fuelling, it appears that the boiler is being fired at 20% to 22% of its capacity. This indicates that, with appropriate changes in the fuel feed system and in the Dutch Oven, the boiler output could be increased to several times that measured during monitoring.

5.2.6 Firing Rate: Dutch Oven

Recent work reported by Smith (Ref.3) indicates that energy release rates in the order of 2,500 btu/hr. per square inch of grate surface can be obtained from wood chips burning on horizontal grates. He reported that values twice as high (in the order of 5,000 btu/hr. per square inch) had been obtained in experimental equipement, but that system output was hard to control. Based upon the 2,500 btu/hr. per square inch energy release rate and the grate area within the Dutch Oven, calculations in Appendix 3.6, indicate that the burner is operating at 23% to 25% of its possible output. In this regard, the burner (Dutch Oven) seems well matched in terms of capacity to the boiler. Again, the opportunity exists to increase burner output provided appropriate changes are made in the fuel feed

system.

5.2.7 Capacity Factor

The suggestion to increase the firing rate and boiler output may seem unwarrented in view of the relatively low capacity factors (75.7% and 88.7%) noted during some site visits. It should be noted that the heating load was being met by some combination of both the wood-chip fuelled boiler and the manually-fired stickwood boiler. Because usage and output of the manually-fired boiler was not being monitored, it is not known to what extent or when the manually-fired unit was operating. It is known that the stickwood boiler was in service during both the second and third monitoring site visits, and that therefore its contribution to meeting the heat load decreased that required from the chip-fuelled boiler; this had the effect of decreasing the capacity factor. If the output of the chip-fuelled system is increased, the requirement for the manually stoked, stickwood fuelled system could be reduced or, for much of the heating season, eliminated. It would be incorrect to conclude that the low capacity factors indicate that the present output of the chip-burning system is adequate.

5.3 OBSERVATIONS

5.3.1 Fuel Feed Jams

The results of the sieve analysis of three samples of the chip fuel used at Brookdale Nurseries (Appendix 3.2) all indicate a small percentage by weight of material retained on a 1.25 inch square mesh screen. In some instances, the individual particles are several inches long and wide and perhaps one or two inches thick. Such particles pose a problem especially at the rotary valve through which they must pass at the top of the Dutch Oven.

Two solutions appear to exist. The first is to screen all the fuel in order to remove greatly over-sized pieces. Such a practice is almost essential in order to avoid potential problems at any point in the fuel feed system, and certainly would eliminate the occasional jam at the rotary valve.

The second solution is to remove the rotary valve. This valve was installed in order to prevent possible reverse flow of combustion gases out of the combustion chamber and up into the fuel feed auger. In operation, provided the boiler tubes are cleaned regularly, the induced draft fan maintains an adequate negative over-fire pressure so that leakage of combustion gases is not a problem. Elimination of the rotary valve would remove a known site for fuel jams and would also simplify the equipment

and reduce electrical energy consumption somewhat.

5.3.2 Fuel Distribution Over Grates

Mention is made in section 3.4.2 of an attempt to operate a chip spreading device within the furnace, and of the reason for abandoning it. Lacking a fuel spreader, the chips tend to burn in a pile on one side of the grate. In light of the observations made in 5.2.5 and 5.2.6 concerning firing rates, an attempt should be made to arrange some sort of fuel spreader in order to achieve a more uniform fuel distribution over the grate, and so to obtain greater use of the full grate area. A device similar to the front overfeed spreader stoker (Ref.4) utilizing a paddle-wheel distributor running on a horizontal shaft may be relatively easy and inexpensive to arrange.

5.3.3 Combustion Air Supply

The excess air supplied to the Dutch Oven varied from 50% to 260%, with the higher figure being the more typical. This wide variation reflects the range of moisture contents in the fuel, and especially reflects the non-uniform distribution of fuel over the grate. If changes are made to the fuel feed system to increase the firing rate, it may be that the excess air will decrease. In any event, with the given system, the excess air is presently too high and should be reduced to around 50%; such a reduction has the potential to yield a fuel savings in the order of 15% (Ref.1). Reduced excess air, besides further increasing boiler efficiency, should help to reduce the carry-over of fly-ash particles and the subsequent fouling of boiler tubes reported by the operator.

6.0 COST / BENEFIT ANALYSIS

6.1 Cost Accounting

The complete project cost was $105,055.78 of which $65,573.00 was funded by the Conservation and Renewable Energy Demonstration Agreement sponsored by the N.B. Energy Secretariat and Energy, Mines and Resources Canada. The remaining cost was funded by Brookdale Nurseries. The total cost breakdown is as follows.

1. Capital and Installation Cost	$80,686.63
2. Labour Cost	$11,369.15
3. Performance Monitoring	$5,000.00
4. Information Transfer	$8,000.00
TOTAL COST	$105,055.78

Without project funding Brookdale has added a chipper and a fuel storage building. The cost of these two items was approximately $50,000.

Approximate calculations since completion and during use of the system during 1982-83 seem to agree with earlier estimates of 60% annual fuel savings.

6.2 Simple Payback

1. Wood Heating Cost

Heat Supplied by Wood = (kg of wood)x(heating value kj/kg)x(%eff)

kg of wood = 420 tonnes x 1000 kg/tonne = 420,000 kg

heating value = 15,810 kj/kg (20% moisture content wet basis)

% efficiency = 77% (average boiler efficiency)

Heat Supplied = 420,000 x 15,810 x 0.77 = 5.1 million megajoules

Cost of Wood: 420 tonnes(460 tons) @ $40/ton = $18,400.00

Cost of Electricity: 22,224 kwh x $0.042/kwh = $933.40

Cost of Maintenance: 75 Manhours @ $8.00/manhour = $600.00

TOTAL COST $19,933.40

2. EQUIVALENT OIL

Energy Required = 5.1 million megajoules

$$\text{litres of oil} = \frac{\text{Energy Required}}{(\text{Heating value of Oil}) \times (\%\ \text{Efficiency})}$$

$$\frac{5.11 \times 10E9\ \text{KJ}}{38{,}340\ \text{KJ/litre} \times 0.75} = 177{,}810\ \text{litres}$$

Cost of Oil 177,810 litres @ $0.378/litre = $67,213

ANNUAL SAVING = $67,213 - $19,933.40 = $47,279.60

$$\%\ \text{SAVINGS} = \frac{\$47{,}279.60}{\$67{,}213.00} = 70\%$$

$$\text{ANNUAL PAYBACK} = \frac{\$92{,}055.78}{\$47{,}279.60} = 1.95\ \text{YEARS}$$

7.0 CONCLUSIONS

The overall objective of the project has been met. The wood chip heating system has performed very well over the heating season and has cut the nursery's oil consumption drastically from that of previous years. The automation of the system has made it a very easy system to operate and virtually worry free. The project has served as a demonstration and information on the system has been disseminated to appropriate parties; see Appendix 1.

The total energy costs have been reduced by approximately 70%, with a payback of 1.9 years.

8.0 RECOMMENDATIONS

For future installations, it is recommended that expenditures related to drying the chips be directed to systems in the bulk chip storage area rather than in the day storage bin. The owner's experience over the past heating season has verified this conclusion. Ducting from the existing stack-mounted heat exchanger could be rearranged to supply pre-heated combustion air to the dutch oven.

From the performance monitoring, four recommendations specific to the burner have been suggested:

1. Increase the fuel feed rate by doubling or tripling the auger speed.
2. Remove the rotary air valve.
3. Arrange a spreader device to obtain better fuel distribution over the grate.
4. Test CO2 levels in the combustion gas and, using curves in Ref.1, adjust the combustion air supply to reduce the excess air to about 50%.

The primary target market to replicate this system would be other nurseries, hospitals, and schools presently using oil and experiencing high costs for generated energy.

APPENDIX 1: INFORMATION TRANSFER

Information has been distributed on a one-to-one basis to a steady stream of individuals seeking information on the wood-chip fired-boiler. To generate interest among a specific group of persons, namely other greenhouse operators, a seminar was organized by Brookdale Nurseries and the Energy Secretariat in March 1982.

The one-day event included presentations by knowledgable people on various aspects of the greenhouse business and its energy use. As part of the session, a detailed tour of the operating boiler room and the production areas was included. Also an eight minute video tape was made and shown on the CBC New Brunswick TV program AGRI-NEWS. Presentations of this project and the videotape were made at several conferences and there has been considerable newspaper and radio coverage around the province.

APPENDIX 2: CHIPPER SPECIFICATIONS

BRUKS PTO-DRIVEN TRAILER MOUNTED CHIPPER

Chipper Model		982 MT		1.300 MT	
Infeed Opening		250 X 260 mm		250 X 375 mm	
Max. Rec. Roundwood Diameter		230 mm (9")		230 mm (9")	
PTO/Disc speed		540/1000 RPM		540/770 RPM	
Number of Knives		4		4	
Size of Chips (adjustable)		6 - 12 mm		6 - 12 mm	
Chip Size		6 mm	10 mm	6 mm	10 mm
Feed Rate					
	Meters/Minute	24	40	18	31
	Feet/Minute	78	131	59	101
Chipping Capacity					
	Cubic Meters/hour	29	49	23	38
	Cubic Feet/hour	1020	1720	780	1330
	Tonnes/hour	10.2	17.2	7.8	13.2
Power Required	KW	58	98	46	76
	HP	78	131	62	102
Continuous Feed Capacity					
Cords/Hour (average 4" logs)		5.1	8.6	3.9	6.6

						A3	
Number of Knives		2				2	
Size of Chips (adjustable)		15 - 30 mm				15 - 30 mm	
<u>Chip Size</u>							
Feed Rate							
	-Meters/Minute	32	50			25	38
	-Feet/Minute	105	164			81	12
<u>Chip Capacity /Hour</u> (average 4" logs)							
	-Cubic Meters/hour	39	61			30	47
	-Cubic Feet/hour	1360	2130			1060	1650
	-Tonnes/hour	13.8	21.3			10.6	16.5
Power Required	KW	78	122	61	94		
	HP	104	163	82	126		
<u>Continuous Feed Capacity</u>							
Cords/Hour (average 4" logs)		6.9	10.8	5.3	8.2		
Weight of chipper	kg	1700			2500		

APPENDIX 3: MONITORING DETAILS

APPENDIX 3.1
EQUIPMENT LIST

A EQUIPMENT UNDER TEST:

BOILER: Dominion Bridge Co. Ltd., Lachine, Quebec
Model 250 - 06 - 3
Max. Firing rate 10,500,000 btu/hr
Min. firing rate 3,500,000 btu/hr
Heaviest oil No. 6
Max. Firing Rate (oil) 69.7 US gallons/hr
Nozzle tip 5051; plug M3

DUTCH OVEN: Custom fabricated at Brookdale Nurseries

FUEL HANDLING SYSTEM: Custom fabricated at Brookdale Nurseries

B EQUIPMENT USED FOR TEST PURPOSES:

INPUT MEASUREMENTS:

TIMER: General Time, Thomaston, Conn., USA
Hours and tenths to 99,999.9
P1572A1
LT30437

SCALES: Fairbanks-Morse, Montreal, Canada
240 lb. capacity (0.25 lb. increments)
Code 8
Serial No. D6768

MOISTURE CONTENT DETERMINATION:

OVEN: Blue-M Laboratory Oven, Model SW-11TA
Single wall transite oven
Blue M Electric Company, Blue Island, Illinois, USA

SCALES: Ohaus Heavy Duty Solution Balance
20 kg - 45 lb capacity, 1 g resolution
Ohaus, Florham Park, NJ, USA

ELECTRICITY: (Feed auger, fans, valve, controls)
Demand Energy Meter
Sangamo Model ED30, 1.2-85 amps, 30kW
120 volt, 3 phase, 4 wire, wye connection
Multiplication factor = 20
Serial No. 6544882

OUTPUT MEASUREMENTS:

FLOWMETER: Neptune Meters Ltd.
(Condensate) 1.5 inch Trident, Style 3
Serial No. 26769237

THERMOMETER: Tel-Tru Manufacturing Co., Rochester, NY, USA
(Condensate) GTR500R 4 inch, 0-140 F

PRESSURE GAGE: Bestobell Controls
(Steam) 0-30 psi

CARBON DIOXIDE: Bacharach Instruments, Pittsburgh, PA, USA
(Stack Gas) Fyrite Gas Analyzer
CO2 Indicator Model CND, 0-20% CO2

TEMPERATURE: Tel-Tru Manufacturing Co., Rochester, NY, USA
(Stack Gas) GT-300R 3 inch, 50-500 F

SMOKE DENSITY: Bacharach Instrument Co., Pittsburgh, PA., USA
(Stack gas) True-Spot Smoke Tester, Model RCC-B

STACK DRAFT: Bacharach Instrument Co., Pittsburgh, PA, USA
Draftrite Model 13-3001, Scale +0.06 to -0.26 in water

C OTHER BOILERS:

FRONT BOILER ROOM (two boilers):
-Boiler converted to be fired using wood chips - see section A.
-60 hp Volcano Package Boiler (Starfire) - serial no. 4063S
- Model 4A-60E-G1
- Heating surface 248 sq. ft.
- 15 psi steam
- input 17.5 US Gallons/hr No.2 fuel oil

REAR BOILER HOUSE (three boilers):
-250 hp Volcano Package Boilers (Starfire)
- Serial Nos. 3885GB (oil fired - on-line for stand-by)
3928GB (oil fired - not in use)
3492GB (converted to burn wood)
- Model 4A-250E-M5R
- Heating surface 1003 sq. ft.
- 15 psi steam
- input 71 US Gallons/hr No.2 fuel oil

APPENDIX 3.2
CALIBRATION TESTS - DATA AND RESULTS

FEED AUGER DELIVERY

METHOD
A quantity of the fuel type (cedar chips, hardwood chips) was put into the small surge bin within which diaphragm switches are normally used to control the fuel level. For test purposes, the level of chips was maintained manually between the low and high levels ordinarily experienced under automatic operation. The auger drive was turned on and the auger allowed to run until chips began to enter the cold combustion chamber. The time required to fill a 2 cu. ft. box placed inside the combustion chamber was measured and recorded for four or five replications for each fuel. Fuel samples were taken after each test in order to permit determination of moisture content. After completion of a test run with any one fuel type, the auger was allowed to run until empty in order to purge all chips from the previous run before starting tests on a new fuel type.

Test No.	%mc-dry	time to fill 2 cu ft box mins - secs	box net wt lbs	delivery cu ft/hr	delivery lbs/hr
0.75 in chips - dry - residue in fuel feed system from previous year					
1	15.7	8-49	28.0	13.6	190.5
2	20.7	9-30	28.0	12.6	176.8
3	21.7	8-54	29.75	13.5	200.6
4	19.5	6-50	30.0	17.6	263.4
hardwood chips - dried - intended for use during monitoring period					
5	26.8	7-20	29.0	16.4	237.3
6	-oversized piece jammed rotary air valve - test aborted				
7	24.6	7-30	29.5	16.0	236.0
8	25.0	7-20	28.75	16.4	235.2
9	24.4	7-35	30.25	15.8	239.3
AVERAGES	25.2			16.15	237.0
MASS OF DRY FIBRE PER HOUR (AVERAGE) = 189.3 lbs/h					
cedar chips - green - intended for use during early heating season					
10	53.4	8-15	25.75	14.5	187.3
11	50.0	8-06	26.0	14.8	192.6
12	55.7	7-12	26.25	16.7	218.75
13	50.0	7-45	27.0	15.5	209.0
14	54.3	7-32	26.5	15.9	211.1
AVERAGES	52.7			15.5	203.8
MASS OF DRY FIBRE PER HOUR (AVERAGE) = 133.5 lbs/h					

STEAM PRESSURE GAGE READINGS
Bestobell Controls, 0-30 psi bourdon tube gage

Test	Dead-weight Gage Tester Pressure psi	Pressure Gage Reading Loading psi	Unloading psi
1	5.0	5.0	5.0
2	10.0	10.25	10.25
3	15.0	15.25	15.5
4	20.0	20.25	20.5
5	25.0	25.25	25.25
6	30.0	29.75	-

CONDENSATE TEMPERATURE GAGE
Tel-Tru Model GT500R, 4 inch, 0-140 F

Tel-Tru Gage F	Thermocouple F	Difference F
32.8	31.7	1.1
38.5	37.3	1.2
46.0	45.0	1.0
56.0	54.7	1.3
66.0	64.5	1.5
78.4	77.0	1.4
89.0	87.3	1.7
100.0	98.3	1.7
108.0	106.5	1.5
118.0	116.6	1.4
124.0	122.6	1.4
130.0	128.6	1.4
136.0	134.6	1.4
AVERAGE		1.4

REMARKS: The Tel-Tru thermometer was found to read high by an average of 1.4 F over its entire range, and so was adjusted to eliminate this error.

CONDENSATE FLOW METER
Neptune, 1.5 inch, water meter - serial no. 26769237

City of Fredericton, Water Department
Water Meter Test Report - dated 84 09 11
- test by R. McArthur

New Reading 468,000 imperial gallons
Old " 465,000 imperial gallons

Test results	Full flow	Intermediate flow	Low flow
	75 gpm	3 gpm	1 gpm
Accuracy	100 %	100 %	99.9 %

Average performance per A.W.W.A Standards = 99.96 %

REMARKS: This meter was tested and found to be well within standards of a cold water meter. Standards set by A.W.W.A. as above (Average 98% to 102%).

CO2 TESTER
New solution used. Calibration checked per manufacturer's instructions.

TIMER
BENCH TEST CHECK No. 1 - continuous operation
84 12 09 13:47 hours to 84 12 21 10:27 hours = 284.8 hours

Timer reading at start = 10,085.2 hours
at end = 10,369.8 hours
Accumulated time = 284.6 hours

Difference - clock time and timer reading = 0.2 hours

Timer percent error = (0.2/284.8)(100) = 0.07 % slow

BENCH TEST CHECK No. 2 - continuous operation
85 01 23 22:30 hours to 85 01 24 09:00 hours = 10.5 hours

Timer reading at start = 10,369.8 hours
at end = 10,379.6 hours
Accumulated time = 9.8 hours

Difference - clock time and timer reading = 0.7 hours

Timer percent error = (0.7/10.5)(100) = 6.7 % slow

CONCLUSIONS - timer performance is erratic
- timer tends to read low
- fuel consumption estimated from timer readings is probably low

APPENDIX 3.3
FUEL CHARACTERIZATION - PARTICLE SIZE DISTRIBUTION

Samples taken 83 09 22 during auger delivery tests

	SAMPLE NO. 1			SAMPLE NO. 2			SAMPLE NO. 3		
Screen size in	Weight g	%	Acc. %	Weight g	%	Acc. %	Weight g	%	Acc. %
1.25	31	0.8	0.8	20	0.7	0.7	25	1.1	1.1
1.0	413	10.7	11.5	24	0.8	1.5	71	3.3	4.4
0.75	1320	34.3	45.8	265	8.9	10.4	296	13.7	18.1
0.5	960	24.9	70.7	981	33.1	43.5	526	24.3	42.4
0.375	599	15.6	86.3	626	21.1	64.6	421	19.5	61.9
0.3125	181	4.7	91.0	278	9.4	74.0	182	8.4	70.3
pan	345	9.0	100.0	773	26.0	100.0	643	29.7	100.0
TOTALS	3849	100.0		2967	100.0		2164	100.0	

APPENDIX 3.4
OVERALL CHIP-BURNING SYSTEM PERFORMANCE
1983-84 HEATING SEASON

TOTAL MONITORED PERIOD

1983 10 24 - all instrumentation in place and functioning
1984 05 26 - final spot check site visit
TOTAL MONITORED PERIOD = 7 months

NOTES: (1) The total monitored period does not span the entire heating season. The condensate flow meter originally installed in the system was found to be defective during pre-monitoring instrument calibration, and a replacement meter was installed on 83 10 20. The totalizing running time meter installed and tested on 83 09 22 (prior to start of heating season) was found to be inoperative on 83 10 20 and so was replaced on 83 10 24, at which date it was possible to begin monitoring. It is estimated that a three week period in early October was missed.

(2)The totalizing timer indicated 10,085.2 hours when removed from the system on 84 09 06, thus showing a further 26.0 hours beyond the reading noted at the end of the 1984 05 26 site visit. Since the chip-fuelled boiler was only being fired at night towards the end of the heating season, it is estimated that the 26.0 hours represents about 3 days of operation beyond the date of the final monitoring site visit.

TOTAL RUNNING TIME

1983 10 24 - start monitoring - monitor timer	6,174.5 hours
1984 05 26 - end monitoring - end of heating	10,085.2 hours
TOTAL RUNNING HOURS OVER MONITORED PERIOD	3,910.7 hours

TOTAL FUEL CONSUMPTION

Lacking records to show precisely which fuel type - cedar, dried hardwood or undried hardwood chips - were being used, it is not possible to break the total operating period into segments of known length within each of which a specific fuel type was used. Therefore, in order to approximate the total mass of fuel used over the test period, the auger delivery rate as determined for dried hardwood chips is used (237 lbs/hr). This assumption is made based on the observed small quantities of cedar and undried hardwood chips relative to the dried hardwood chips in storage at the start of the heating season. The undried hardwood chips were produced in late October or November, 1983, after the auger flow rate calibration tests had been performed; consequently hard data regarding feed rate for these chips is not available. Undried hardwood chips were burned starting on or about 84 03 02.

ESTIMATED TOTAL MASS OF CHIPS CONSUMED OVER MONITORED PERIOD IS:

MASS (lbs) = TOTAL HOURS x AUGER MASS DELIVERY RATE

= (3,910.7)(237)

MASS = 926,800 lbs of 25% mc (dry basis) hardwood chips
or
MASS = 460 short tons of 25% mc (dry basis) h.dwood chips
or
MASS = 420 tonnes of 25% mc (dry basis) hardwood chips

TOTAL POUNDS OF STEAM PRODUCED

83 10 24 - start monitoring - flow meter reading = 5,308 Imp Galls
84 05 26 - end monitoring - flow meter reading = 467,821 Imp Galls
TOTAL GALLONS HEATED OVER MONITORED PERIOD = 462,513 Imp Galls

At 10.0 lbs/Imp Gallon, total mass of water heated and hence total mass of steam produced is:

LBS. STEAM PRODUCED = 4,625,130 lbs

TOTAL ELECTRICAL ENERGY CONSUMED

83 10 24 - start - kW.h meter reading = 4810.0 x 20 = 96,200 kW.h
84 05 26 - end - kW.h meter reading = 6021.2 x 20 = 120,424 kW.h
TOTAL ELECTRICAL ENERGY CONSUMED = 24,224 kW.h

APPENDIX 3.5
BURNER AND BOILER PERFORMANCE - 24 HOUR SPOT CHECK
1983-84 HEATING SEASON
TEST CONDUCTED 1983 11 21-22

DATA RECORDED DURING TEST

Time of Day	Timer Hours	Condensate Temp F	Condensate Flow Imp Gall	Steam press psi	Electrty consumed kW.h	Fuel %mc dry	Stack Gas CO2 %	Stack Gas Temp F	Stack Gas Smoke No.
83 11 21									
19:09	6725.63	84.5	67914	7.9	4965	45.2	12.0	280	-
22:16	6728.38	88.0	68263	5.5	4965.65	47.2	10.5	280	1
22:44							11.0	280	1
83 11 22									
01:15	6730.63	89.0	68573	5.4	4966.34	38.7	10.5	280	1
05:50	6733.7	89.5	68929	6.5	4967.33	37.5	9.75	280	1
06:09							11.5	280	
08:35	6735.93	90.5	69200	4.25	4967.92	40.5	10.75	280	1
11:04	6737.45	90.5	69400	7.25	4968.4	37.3	off*	255	-
12:18						38.3	off*		
14:01	6739.09	86.5	69582	6.5	4969.0	37.5	12.0	280	1
15:04	6739.85	85.5	69707	5.25	4969.24	38.0	12.5	280	1
16:05	6740.81	84.5	69821	6.2	4969.5	36.7	12.75	280	1
17:03	6741.72	83.5	69937	6.0	4969.71		12.5	285	1
18:05	6742.75	83.5	70051	4.5	4970.0	37.4	13.0	280	1
18:59	6743.64	83.5	70170	5.75	4970.2	37.2	11.5	280	1
AVERAGES		86.5		5.9		39.3			

Check draft: over-fire draft = -0.03 to -0.04 in water at right front duct
air plenum - over scale of instrument - not measured
at breeching = -0.25 in water

* stoker not running - fire very low (glowing embers only) - at 11:04 and 12:18

CALCULATION OF OVERALL PERFORMANCE
- 19:09 hours 83 11 21 to 18:59 hours 83 11 22

BOILER OUTPUT

Lbs. steam generated = (70,170 - 67,914)(10) = 22,560 lbs

Average steam pressure = 5.9 psig
= 20.6 psia

Enthalpy of dry, saturated steam (hg) is:-
hg = 1156.8 btu/lb

Average condensate temperature = 86.5 F

Enthalpy of condensate supplied to boiler = 54.5 btu/lb

Boiler thermal output = (hg - hf)(lbs steam generated)
= (1156.8 - 54.5)(22560)
= 24,868,000 btu

ENERGY INPUT

Fuel supplied = (end time-start time)(lbs dry fibre/hour) -- using fuel feed rate from calibration test results

= (6743.64 - 6725.63)(189.3)
= (18.01)(189.3)
= 3,409.3 lbs dry fibre

Energy input to burner = (dry fibre supplied)(8,600 btu/lb)
= (3,409.3)(8,600)
= 29,320,000 btu

EFFICIENCY

Overall thermal efficiency = (boiler thermal output)/(energy input to burner)
= (24,868,000)/(29,320,000)
= 0.848

Percent efficiency = 84.8 % - based on higher heating value of fuel

Efficiency (stack loss method) from stack gas CO2 and temperature, and fuel moisture content:

Average %mc of 39.3% dry basis is 28.2% wet basis
At 9.75% CO2 and 280 F, from curves in (1)- using curves for 30% mc:
Excess air is approximately 100 %
Estimated boiler efficiency is 77 %

At 13.0% CO2 and 280 F, from curves in (1) - using curve for 30% mc:
Excess air is approximately 50 %
Estimated boiler efficiency is 79 %

CAPACITY FACTOR

Capacity factor (%) = [(hours run)/(total possible hours)](100)
= [(18.01)/(23.8)](100)
= 75.7 %

FIRING RATE

Measured firing rate = (energy to burner)/(time over which energy was supplied)

= (29,320,000)/(18.01)
= 1,628,000 btu/h

Boiler is rated at 10,500,000 btu/h maximum firing rate when oil fired. If it is assumed that the boiler is derated to 70% of maximum (7,350,000 btu/h) when wood fired, then at 1,628,000 btu/h, the boiler is operating at (1,628,000)(100)/(7,350,000) = 22% of its possible input.

Burner grate is 36 in by 72 in and so has an area of 2,592 sq in. Current experience with wood-chip burners indicates that an energy release rate of 2,500 btu/h per square inch of grate area is readily achieved. At this rate, the burner should be able to deliver (2,592)(2,500) = 6,480,000 btu/h. The maximum firing rate (above) is 1,628,000 btu/h, or 25% of the burner's possible output.

APPENDIX 3.6
BURNER AND BOILER PERFORMANCE - 24 HOUR SPOT CHECK
1983-84 HEATING SEASON
TEST CONDUCTED 1984 03 05-06

DATA RECORDED DURING TEST

Time of Day	Timer Hours	Condensate Temp F	Condensate Flow Imp Gall	Steam press psi	Electrty consumed kW.h	Fuel %mc dry	Stack Gas CO2 %	Stack Gas Temp F	Stack Gas Smoke No.
84 03 05									
15:00	Fire kindled (manually) - boiler just cleaned								
16:08	8690.48	90.0	320505	6.25	5559.5	68.5	5.5	240	1
20:03	8694.3	86.0	320910	5.5	5560.8	73.5	7.75	244	0
84 03 06									
00:07	8697.7	85.0	321245	6.1	5561.8	75.3	5.75	240	1
04:09	8701.05	86.5	321623	7.0	5562.9	70.1	6.5	248	1
08:06	8704.65	89.0	322037	5.5	5564.1	74.7	7.75	245	1
15:45	8708.75	87.5	322429	10.75	5565.6	SEE NOTE BELOW			
AVERAGES		87.3		6.1		72.4			

NOTE: high steam pressure due to operation of manually fired stickwood boiler caused fuel-feed auger to stop automatically. Fire out. Readings taken at 15:45 hours not used in calculations.

Check draft: at breeching = -0.21 in water (all tests)

CALCULATION OF OVERALL PERFORMANCE
- 16:08 hours 84 03 05 to 08:06 hours 84 03 06

BOILER OUTPUT
Lbs. steam generated = (322,037 - 320,505)(10) = 15,320 lbs

Average steam pressure = 6.1 psig
= 20.8 psia
Enthalpy of dry, saturated steam (hg) is:-
hg = 1157 btu/lb

Average condensate temperature = 87.3 F

Enthalpy of condensate supplied to boiler = 55.3 btu/lb

Boiler thermal output = (1157 - 55.3)(15,320)
= 16,878,000 btu

ENERGY INPUT

Fuel supplied = (end time-start time)(volume/time)(density at mc)
= (14.17)(16.15)(18.59)
= (8704.65 - 8690.48)(16.15)(18.59)
= 4,254.2 lbs as fired

Dry fibre supplied = (fuel supplied)/(1 + (mc/100))
= (4,254.2)/(1.724)
= 2,467.7 lbs dry fibre

Energy input to burner = (dry fibre supplied)(8,600 btu/lb)
= (2,467.7)(8,600)
= 21,222,000 btu

EFFICIENCY

Overall thermal efficiency = (boiler thermal output)/(energy input to burner)
= (16,878,000)/(21,222,000)
= 0.795
Percent efficiency = 79.5 % - based on higher heating value of fuel

Efficiency (stack loss method) from stack gas CO2 and temperature, and fuel moisture content:

Average %mc of 72.4% dry basis is 42% wet basis
At 5.5% CO2 and 240 F, from curves in (1):
Excess air is approximately 260 %
Estimated boiler efficiency is 71 %

At 7.75% CO2 and 245 F, from curves in (1):
Excess air is approximately 160 %
Estimated boiler efficiency is 73 %

CAPACITY FACTOR

Capacity factor (%) = [(hours run)/(total possible hours)](100)
= [(14.17)/(15.97)](100)
= 88.7 %

FIRING RATE

Measured firing rate = (energy to burner)/(time over which energy was supplied)

= (221,222,000)/(14.17)
= 1,498,000 btu/h

Boiler is rated at 10,500,000 btu/h maximum firing rate when oil fired. If it is assumed that the boiler is derated to 70% of maximum (7,350,000 btu/h) when wood fired, then at 1,498,000 btu/h, the boiler is operating at (1,498,000)(100)/(7,350,000) = 20% of its possible input.

Burner grate is 36 in by 72 in and so has an area of 2,592 sq in. Current experience with wood-chip burners indicates that an energy release rate of 2,500 btu/h per square inch of grate area is readily achieved. At this rate, the burner should be able to deliver (2,592)(2,500) = 6,480,000 btu/h. The maximum firing rate (above) is 1,498,000 btu/h, or 23% of the burner's possible output.

APPENDIX 3.7
BURNER AND BOILER PERFORMANCE - 24 HOUR SPOT CHECK
1983-84 HEATING SEASON
TEST CONDUCTED 1984 05 23-24

DATA RECORDED DURING TEST

Time of Day	Timer Hours	Condensate Temp F	Condensate Flow Imp Gall	Steam press psi	Electrty consumed kW.h	Fuel %mc dry	Stack Gas CO2 %	Stack Gas Temp F	Stack Gas Smoke No.
84 05 23									
23:15	10051.8	77.5	464736	0.25	6018.2	56.3	-	-	-
Fire kindled (manually) - boiler known to be in need of cleaning - smoke leaking from burner into boiler room - readings not used in calculations									
84 05 24									
01:08	10053.6	76.0	464795	8.0	6018.7	53.7	3.0	235	8
03:03	10054.2	75.5	464869	6.25	6019.1	55.2	8.75	235	1
05:30	10055.5	75.0	465020	6.5	6019.6	58.6	8.5	230	3
10:44	10058.25	79.0	465240	8.0	6020.9	58.1	not running		
12:35	10058.9	79.5	465312	7.0	6021.1	58.2	not running		
13:20	10059.2	80.0	465351	6.0	6021.2	53.9	not running		
AVERAGES		77.5		7.0		56.3			

NOTES:(1) 84 04 23 - sunny - heat not required from chip burner - stickwood boiler in use - chip-fuelled boiler fired up at 23:00 hours to permit testing, otherwise probably would not have been used.

(2) 84 04 24 - cloudy and rain - chip unit left on and running at 13:20 hours despite earlier advice that it would be shut down at 06:00 hours.

(3) stack gas samples not taken during last three observations since stoker was not running then. Glowing coals on grate, but no open fire.

Check draft: at breeching = -0.18 to -0.22 in water (all tests)

CALCULATION OF OVERALL PERFORMANCE
- 01:08 hours 84 05 24 to 13:20 hours 84 05 24

BOILER OUTPUT

Lbs. steam generated = (465,351 - 464,795)(10) = 5,560 lbs

Average steam pressure = 7.0 psig
= 21.7 psia

Enthalpy of dry, saturated steam (hg) is:-
hg = 1157.8 btu/lb

Average condensate temperature = 77.5 F

Enthalpy of condensate supplied to boiler = 45.5 btu/lb

Boiler thermal output = (1157.8 - 45.5)(5,560)
= 6,184,000 btu

ENERGY INPUT

Fuel supplied = (end time-start time)(volume/time)(density at mc)
= (10,059.2 - 10,053.6)(16.15)(17.87)
= (5.6)(16.15)(17.87)
= 1,616.2 lbs as fired

Dry fibre supplied = (fuel supplied)/(1 + (mc/100))
= (1,616.2)/(1.563)
= 1,034.0 lbs dry fibre

Energy input to burner = (dry fibre supplied)(8,600 btu/lb)
= (1,034.0)(8,600)
= 8,892,000 btu

EFFICIENCY

Overall thermal efficiency = (boiler thermal output)/(energy input to burner)
= (6,184,000)/(8,892,000)
= 0.695

Percent efficiency = 69.5 % - based on higher heating value of fuel

Efficiency (stack loss method) from stack gas CO2 and temperature, and fuel moisture content:

Average %mc of 56.3% dry basis is 36% wet basis
At 3.0% CO2 and 235 F, from curves in (1) for 40% mc:
- not possible to determine efficiency at this low a CO2 level
- excess air very high and efficiency low

At 8.75% CO2 and 235 F, from curves in (1) for 40% mc:
Excess air is approximately 130 %
Estimated boiler efficiency is 75 %

CAPACITY FACTOR

Capacity factor (%) = [(hours run)/(total possible hours)](100)
= [(5.6)/(12.2)](100)
= 45.9 %

FIRING RATE

Measured firing rate = (energy to burner)/(time over which energy was supplied)

= (8,892,000)/(5.6)

= 1,588,000 btu/h

Boiler is rated at 10,500,000 btu/h maximum firing rate when oil fired. If it is assumed that the boiler is derated to 70% of maximum (7,350,000 btu/h) when wood fired, then at 1,588,000 btu/h, the boiler is operating at (1,588,000)(100)/(7,350,000) = 22% of its possible input.

Burner grate is 36 in by 72 in and so has an area of 2,592 sq in. Current experience with wood-chip burners indicates that an energy release rate of 2,500 btu/h per square inch of grate area is readily achieved. At this rate, the burner should be able to deliver (2,592)(2,500) = 6,480,000 btu/h. The maximum firing rate (above) is 1,588,000 btu/h, or 25% of the burner's possible output.

APPENDIX 4: REFERENCES

1 Roberts, John, Fred Austin, A. T. Rossano, Jay Willenberg. Measuring and Improving the Efficiency of Large Wood-Fired Furnaces: Impact on Emissions and Fuel Use. Proc. of 1981 International Conf. on Residential Solid Fuels. Portland, Oregon. June 1981.

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3 Smith, Norman. Wood-Chip Furnace Developments at the University of Maine. Proc. Wood Energy Symposium. N. B. Energy Secretariat. Fredericton, N.B. February, 1983.

4 MacNaughton, E. Elementary Steam Power Engineering. 3rd Edn. John Wiley. New York. 1961.